

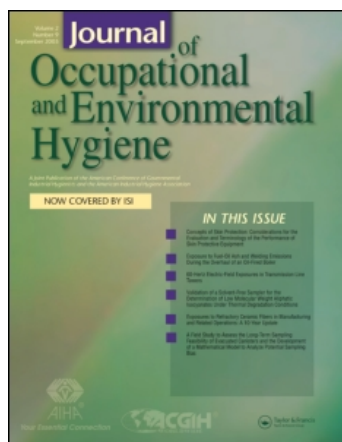
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Daniel C. Tranter^a; Amanda Teresa Wobbema^b; Kathleen Norlien^a; Dale F. Dorschner^a

^a Minnesota Department of Health, Division of Environmental Health, St. Paul, Minnesota ^b Blue Cross and Blue Shield of Minnesota, Health Care Informatics, Eagan, Minnesota

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Indoor Allergens in Minnesota Schools and Child Care Centers

Daniel C. Tranter,¹ Amanda Teresa Wobbema,² Kathleen Norlien¹
and Dale F. Dorschner¹

¹Minnesota Department of Health, Division of Environmental Health, St. Paul, Minnesota

²Blue Cross and Blue Shield of Minnesota, Health Care Informatics, Eagan, Minnesota

Elevated concentrations of allergens in the indoor environment may cause allergic sensitization and symptoms. Occupant exposure to indoor allergens in educational facilities should and can be controlled. This study (1) assessed the presence of indoor allergens in Minnesota schools and child care centers, (2) characterized the distribution of allergens in different materials, and (3) evaluated the effect of building and maintenance interventions on allergen concentrations. Settled dust samples were collected from carpet, vinyl tile floors, and upholstered furniture in six schools and seven child care centers before and after interventions. Interventions included changes to cleaning, ventilation, entry mats, furnishings, flooring, and classroom items. The amount of total dust, culturable fungi, and indoor allergens—cockroach, dust mite, cat, and dog—were quantified in the dust samples. Cockroach and dust mite allergens were generally low and below the detection limit, but one dust mite allergen was detected in some areas. Cat and dog allergens were frequently detected at elevated levels, with half the samples above the provisional sensitization risk thresholds and a few samples above the symptom thresholds. Allergen concentrations were highest in upholstered furniture, followed by carpeting and then vinyl floor tile. Cat and dog allergens were lower after the interventions. Cat and dog allergens, but not dust mite and cockroach allergens, seem to be ubiquitous in child care and elementary schools of the U.S. Midwest. These allergens may contribute to sensitization in atopic individuals and occasionally cause symptoms in sensitized allergic individuals. Fleecy materials that are not adequately cleaned, such as upholstered furniture, appear to be the most significant allergen reservoirs. Modest environmental interventions can be implemented by building staff, which should result in lower allergen concentrations.

Keywords asthma triggers, environmental interventions, indoor environmental quality

INTRODUCTION

Controlling allergen exposure is an important component of managing allergies. While the home environment is the likely primary site of exposure to indoor allergens, public buildings can also contribute to symptoms, especially where effective strategies to control allergens in the home have been implemented. The indoor environments of schools⁽¹⁾ and child care facilities^(2–13) can have significant levels of indoor allergens, including cat, dog, dust mite, and cockroach allergens.

While the presence of allergens in educational facilities is well documented, there are minimal data regarding allergens in educational facilities in the upper Midwestern region of the United States (with the exception of those in Ramachandran et al.).⁽¹⁴⁾ The relative role of building materials in schools as reservoirs of allergens has received little scrutiny. Finally, only a few studies have measured the longitudinal impact of modest interventions in educational facilities on the level of indoor allergens; most studies were cross-sectional and correlated allergens to building, maintenance, and other environmental variables at a given moment in time.

This study (1) investigated the levels of indoor allergens in Minnesota educational facilities; (2) compared levels in different building materials and furnishings; and (3) measured allergen concentrations following modest institutional changes primarily in cleaning, ventilation, furnishings, flooring, entry mats, and classroom items.

METHODS

Selection of Facilities

Elementary schools and child care centers were recruited through a direct mailing to every public school district in Minnesota (341 total) and every licensed child care center in Minneapolis, Minnesota (94 total). Fourteen school districts and 12 child care centers applied to participate.

Applications were evaluated to ensure facilities were (1) representative of all Minnesota schools and child care centers

Address correspondence to: Daniel C. Tranter, Minnesota Department of Health, Division of Environmental Health, P.O. Box 64975, St. Paul, MN 55164-0975; e-mail: daniel.tranter@state.mn.us.

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and (2) had resources to implement changes. The facilities were selected according to the following criteria: commitment to fully participate in all aspects of the project (interviews, surveys, trainings, interventions); motivation of building staff to address indoor environmental problems; number of children and staff with asthma; a consistent enrollment rate; diversity in occupant numbers, construction characteristics, and types of ventilation; geographic distribution (schools only); and the presence of building materials needed for sampling. Six elementary schools were selected to participate, located in suburban and rural Minnesota; seven child care centers located in Minneapolis were selected.

Sample Collection

Dust samples were collected from carpet, vinyl tile floors, and upholstered furniture. In schools, samples were collected from carpet and vinyl tile floor during January–February (baseline) and again at the same locations one year later (follow-up 12 months). In child care centers, samples were collected from carpet and upholstered furniture during July–August (baseline), January–February (follow-up 6 months), and July–August (follow-up 12 months).

A total of 204 samples were collected. Sixty samples were collected in the child care centers (20 samples on three occasions), and 144 samples were collected in the elementary schools (72 samples on two occasions). Samples were collected from classrooms that were used most frequently and had the highest occupancy levels. Samples were collected in the late afternoon after children left the rooms and before routine cleaning was performed.

Dust samples were collected by vacuuming surfaces at a rate of 1 min/m² with a GAST Rotary Vane Vacuum Pump (#1531; GAST, Inc., Benton Harbor, Mich.) at 15 L/min airflow. Materials were vacuumed by stroking each sampling area in four directions, each for one-quarter of the sampling duration. The flow rate was verified with a field rotometer (P/N 320–4A20L; SKC Inc., Eighty Four, Pa.) before and after sampling. Each dust sample was collected in a 3-piece, 37-mm cassette with a 0.8 micrometer polyvinyl chloride filter (P/N 738PVC; Zefon International, Inc., Ocala, Fla.). For carpet and furniture, 2 m² were vacuumed per sample. For vinyl tile, additional surface areas were vacuumed until sufficient dust was collected (total of 4–6 m²). Samples were stored at –20°C until shipping.

Allergens were quantified in each sample by a commercial laboratory accredited by AIHA and the American Association for Laboratory Accreditation (A2LA), which follows quality assurance and control measures that meet ISO 17025 Guidelines. Dust samples were sieved through a 355- μ m pore mesh and extracted in 2.0 mL phosphate buffered saline with 0.05% Tween, pH7.4. Samples were centrifuged, and supernatants were analyzed for allergens.

The following allergens were quantified: *Blattella germanica* cockroach (Bla g 1), *Felis domesticus* cat, (Fel d 1), *Canis familiaris* dog (Can f 1), and *Dermatophagoides farinae* dust mite (Der f 1), and *D. pteronyssinus* dust mite (Der

p 1). Samples were analyzed using monoclonal antibodies (Indoor Biotechnologies, Charlottesville, Va.) and the Enzyme Linked Immunosorbent Assay (ELISA) method described elsewhere.^(15–17) In addition, culturable fungi were quantified in the school samples by culturing a portion of each dust sample on 2% malt extract agar (MEA) at 25°C.

Observational Environmental Assessment and Interventions

An observational environmental assessment was conducted on the same days that dust samples were collected. Building staff were interviewed, and a walk-through inspection was completed of all accessible interior spaces and the ventilation system. Building conditions, practices, and policies were assessed that could contribute to the presence of allergens and irritants. The presence of each problem was identified using predefined criteria. The observational assessment parameters are shown in Table I.

Baseline findings from the building evaluations and dust sampling were analyzed and summarized into educational reports for each school and center. Each report included a unique set of recommendations to control and prevent allergens and irritants in the buildings. They were submitted to each facility about 3 months after the baseline assessments. Building staff were educated about findings and recommendations at each facility through on-site training sessions. No funding was provided to implement recommendations; building staff were asked to implement changes using existing resources. Building staff had about 9 months to implement the interventions before the 12-month follow-up evaluations were completed.

For further details about the building evaluations and interventions, see the school (Model Asthma Plan) and child care providers links at <http://www.health.state.mn.us/divs/eh/air/index.htm>.

Descriptive and Statistical Analyses

For the descriptive analysis of concentrations ranges, all the data from schools and child care centers were pooled, including all the sampling occasions (Figure 1). Data were expressed in mass fraction of allergen in floor dust (μ g/g or allergen units/g) and organized into ranges that correspond to proposed provisional risk thresholds for allergic sensitization and asthma symptoms.

The thresholds are defined as follows: (1) dust mite: sensitization ≥ 2.0 μ g/g, symptoms ≥ 10.0 μ g/g, (2) cockroach: sensitization ≥ 2 units/g, symptoms ≥ 8 units/g, (3) cat: sensitization ≥ 1.0 μ g/g, symptoms ≥ 8.0 μ g/g, (4) dog: sensitization ≥ 2.0 μ g/g, symptoms ≥ 10.0 μ g/g. These thresholds have been proposed in a U.S. Housing and Urban Development manual.⁽¹⁸⁾ Sensitization guidelines apply to atopic individuals (i.e., genetically predisposed to allergies). Further information about allergic sensitization and symptom thresholds can be found in the literature.^(18–25)

For the analyses of buildings surfaces and interventions, schools and child care centers were analyzed separately because there were some potentially significant differences

TABLE I. Observational Environmental Assessment Parameters

Indoor Environmental Quality Practices Questionnaire (162)	Interior Walk-Through Inspection Checklist (155)	Ventilation Inspection Checklist (51)
General operations and maintenance (11)	Odors (9)	Outdoor air intake (9)
Heating, ventilation, air conditioning (16)	Cleanliness (11)	Dampers (3)
Smooth flooring maintenance (8)	Furniture and materials (11)	Mechanical room (5)
Carpet flooring maintenance (14)	Diaper changing area (6)	Mechanical unit (6)
General cleaning activities (19)	Soft toys (3)	Filters (6)
Disinfection and sanitation (13)	Plants and animals (7)	Heating and cooling coil areas (3)
Pests and pesticides (12)	Clutter (4)	Condensate drip pans (7)
Chemicals (9)	Art supplies (11)	Ductwork (6)
Construction and renovation (14)	Personal items (9)	Supply and return fans (6)
Furnishing and materials (5)	Maintenance and cleaning supplies (14)	
Plants and animals (10)	Food and waste management (6)	
Smoking (2)	Structural disrepair (3)	
Moisture management (13)	Heating and ventilation (11)	
Food use and storage (2)	Exhaust ventilation (4)	
Hand washing (9)	Water sources (8)	
Outdoor pollutant exposure (5)	Water stains or microbial growth (11)	
	Moisture problem risk (7)	
	Floor drain (2)	
	Vacuum cleaner (7)	
	Signs of uncontrolled pests (6)	
	Floor covering-entrance (5)	

Note: Numbers in parentheses indicate number of questions or issues checked.

between the schools and child care, including types of surfaces sampled, seasons sampled, demographics of occupants, and building ventilation. Allergens were analyzed as allergen surface density ($\mu\text{g}/\text{m}^2$) because this is a better metric in evaluating the total allergen burden in an area and the effect of environmental changes.

In the child care centers, 6-month winter results were excluded in the statistical analyses of change due to the possible confounding influence of season.^(26,27) The dust mite

and cockroach allergens were excluded from these analyses because most of these data were below the detection limit. Concentrations below the detection limits were imputed as 0.5 times the detection limit—3% of cat allergen and 13% of dog allergen values were below the detection limit. Median values rather than means are reported because data were not normally distributed.

Three types of statistical tests were performed. Correlation of allergen surface density to mass fraction of allergen

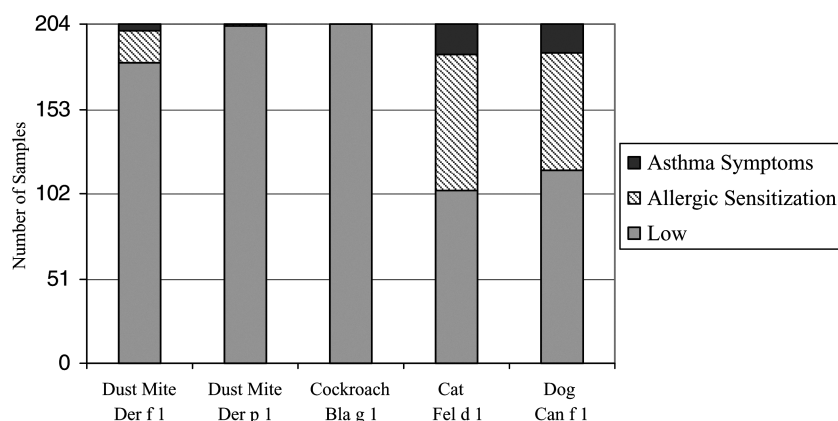


FIGURE 1. Numbers of samples that exceeded provisional thresholds (N = 204)

TABLE II. Comparison of Carpet and Vinyl Floor Tile in Schools

Contaminant	Median (Inter-Quartile Range)		Mann-Whitney U-Test p-value
	Carpet	Tile	
N	79	65	
Cat ($\mu\text{g}/\text{m}^2$)	0.28 (0.14–0.77)	0.014 (0.0063–0.027)	<0.0001
Dog ($\mu\text{g}/\text{m}^2$)	0.45 (0.23–1.4)	0.030 (0.014–0.053)	<0.0001
Dust (g/m^2)	0.27 (0.17–0.37)	0.0305 (0.019–0.063)	<0.0001
Fungi (cfu/ m^2)	18,000 (8,000–61,000)	960 (500–2,700)	<0.0001

in floor dust was analyzed using linear regression with analysis of variance (ANOVA). Surfaces (carpet vs. tile and carpet vs. upholstered furniture) were compared using the Mann-Whitney U Test because data were nonparametric and unmatched. Follow-up concentrations were compared to baseline concentrations using the Sign Test because these data were nonparametric but matched (the exact same locations were sampled at baseline and then follow-up). Twelve-month and not 6-month follow-up data were statistically analyzed in the child care centers to remove the confounding effect of season. In all the analyses, the level of significance was set at a p-value of 0.05.

RESULTS

Allergen Concentrations

Samples were collected from carpet ($n = 121$), vinyl tile ($n = 65$), and upholstered furniture ($n = 18$), with most samples collected during the winter ($n = 164$). All the data were pooled together to provide an overall perspective about levels relative to provisional risk thresholds (Figure 1).

All the samples had cockroach allergen concentrations below the detection limit except one sample that was 0.9 units/g. Most of the dust mite allergen levels were also low, but dust mite allergens differed by species. The median Der p 1 concentration was 0.2 $\mu\text{g}/\text{g}$ (range 0.2–2.6), while the median Der f 1 concentration was 0.4 $\mu\text{g}/\text{g}$ (range 0.2–18). Only one sample had Der p 1 allergens levels ≥ 2.0 $\mu\text{g}/\text{g}$, while 23/204 samples had Der f 1 concentrations above this threshold.

Cat and dog allergens were frequently present at elevated levels in both schools and child care centers. The median cat allergen concentration was 0.91 $\mu\text{g}/\text{g}$ (range 0.06–36). A large number of samples were elevated: 82 samples were in the range 1.0–7.9 $\mu\text{g}/\text{g}$ and 18 samples were ≥ 8.0 $\mu\text{g}/\text{g}$. Dog allergen levels were similar to cat allergen levels. The median dog allergen concentration was 1.52 $\mu\text{g}/\text{g}$ (range 0.2–30), with 71 samples in the range 2.0–9.9 $\mu\text{g}/\text{g}$ and 17 samples ≥ 10.0 $\mu\text{g}/\text{g}$.

Cat and dog allergen concentrations expressed as allergen surface density ($\mu\text{g}/\text{m}^2$, y variable) correlated with mass fraction of allergen in floor dust ($\mu\text{g}/\text{g}$, x variable). For cat allergen, the linear regression formula was $y = 0.1833x + 0.0988$ ($R^2 = 0.5955$; $p = 1.46 \times 10^{-41}$). For dog allergen, the

linear regression formula was $y = 0.1965x + 0.048$ ($R^2 = 0.5954$; $p = 1.49 \times 10^{-41}$).

Comparisons of Surfaces and Type of Facility

Cat allergen, dog allergen, culturable fungi, and total dust surface density were all significantly higher in school carpeting compared to vinyl floor tile, with concentrations 9–20 times greater in carpeting (Table II). All the differences were statistically significant ($p < 0.0001$). Carpet also had significantly higher levels when contaminants were expressed as mass fraction of allergen in floor dust.

Cat allergen was 3.8-fold higher in upholstered furniture in child care centers compared to carpeting ($p = 0.00071$) (Table III). Dog allergen was 2.4 times higher in upholstered furniture in child care centers compared to carpeting ($p = 0.0119$). Total dust levels, however, were similar in carpet and furniture ($p = 0.325$).

Carpet concentrations in child care centers were not significantly different from carpet concentrations in schools for cat allergen (0.420 $\mu\text{g}/\text{m}^2$ vs. 0.282 $\mu\text{g}/\text{m}^2$; $p = 0.564$); dog allergen (0.441 $\mu\text{g}/\text{m}^2$ vs. 0.446 $\mu\text{g}/\text{m}^2$; $p = 0.560$); and total dust (0.284 $\mu\text{g}/\text{m}^2$ vs. 0.269 $\mu\text{g}/\text{m}^2$; $p = 0.879$). In addition, the concentrations were similar when baseline and follow-up (12 month) were compared separately (p-values ranged from 0.2–0.8).

TABLE III. Comparison of Carpet and Upholstered Furniture in Child Care Centers

Contaminant	Median (Inter-Quartile Range)		Mann-Whitney U-Test p-value
	Carpet	Furniture	
N	42	18	
Cat ($\mu\text{g}/\text{m}^2$)	0.42 (0.14–0.90)	1.6 (0.74–4.0)	0.00071
Dog ($\mu\text{g}/\text{m}^2$)	0.44 (0.18–0.96)	1.1 (0.40–2.2)	0.0119
Dust (g/m^2)	0.28 (0.19–0.42)	0.28 (0.15–0.32)	0.325

TABLE IV. Observations at Follow-Up That Could Affect Allergen Concentrations

Observed Improvement	Mean% Change of No. Rooms	
	Schools	Child Care
Increased air movement in restrooms	11	9
Unobstructed air return	61	0
Increased outdoor mechanical air volume	50	0
Cleaner ventilation filters	−86	33
Superior ventilation filter efficiency	33	0
No filter by-pass	8	33
Larger entrance mats	3	45
Entrance mats installed	0	45
Cleaner entrance and hallway floors	33	36
Cleaner restrooms	42	13
Cleaner classroom floors	84	42
Cleaner ventilation diffusers	3	42
Cleaner furniture, windows	−39	42
Fewer fleecy items	−100	11
Less clutter	−4	4
Fewer stuffed toys	9	−8
Less open shelving	0%	11
Use of HEPA filtered vacuum cleaners	17	79
Better maintenance of vacuum cleaners	17	79
New flooring	−5	44
Less use of chalkboards ^A	−8	11
Food in closed containers ^A	26	100
Fewer plants ^A	59	−67

^AShould impact only total dust levels, not pet allergens.

Concentrations Before and After Interventions

Schools and child care centers were provided a variety of recommendations unique to the needs of each building. Building staff implemented recommendations using their own existing institutional resources. Changes in cleaning, ventilation, furnishings, new flooring materials, and other operational and maintenance practices were observed at follow-up. Not all interventions were implemented in each building, and not all interventions implemented would be expected to impact dust or pet allergens (for example, some interventions targeted chemical irritants).

Table IV lists the observed improvements that would be expected to affect pet allergen and total particulate levels based on prior studies.⁽¹⁾ The change in numbers of rooms where the problem was observed is shown, as a percentage relative to baseline (a negative change means more rooms had the observed problem).

TABLE V. School Allergen Concentration Before and After Interventions

Contaminant	Median		No. Sampling Locations Declined at Follow-Up 12 Mo	Sign Test p-value
	Baseline	Follow-Up 12 Mo		
N	72	72		
Cat ($\mu\text{g}/\text{m}^2$)	0.12	0.066	69%	0.0013
Dog ($\mu\text{g}/\text{m}^2$)	0.18	0.078	68%	0.003
Dust (g/m^2)	0.19	0.12	39%	0.08
Fungi (cfu/ m^2)	8,000	5,400	57%	0.29

In the schools, median cat allergen declined from 0.12 $\mu\text{g}/\text{m}^2$ to 0.07 $\mu\text{g}/\text{m}^2$ at 12-month follow-up with concentrations lower in 69% of sampling locations ($p = 0.0013$) (Table V). In addition, the mass fraction of cat allergen in floor dust declined in 71% of locations ($p = 0.0005$). Median dog allergen also declined from 0.18 $\mu\text{g}/\text{m}^2$ to 0.078 $\mu\text{g}/\text{m}^2$, with concentrations lower in 68% of locations at 12-month follow-up ($p = 0.003$). The mass fraction of dog allergen in floor dust also declined in 68% of locations ($p = 0.003$). Median culturable fungi declined from 8000 cfu/ m^2 to 5400 cfu/ m^2 , but concentrations were lower in only 57% of locations, which was not statistically significant ($p = 0.29$). While the median total dust surface density also declined (from 0.193 g/m^2 to 0.123 g/m^2), concentrations were lower in only 39% of locations ($p = 0.08$).

In the child care centers, median cat allergen concentrations declined from 1.2 $\mu\text{g}/\text{m}^2$ at baseline to 0.20 $\mu\text{g}/\text{m}^2$ at 12-month follow-up, with concentrations lower in 95% of locations ($p = 0.00004$) (Table VI). In addition, the mass fraction of cat allergen in floor dust declined in 90% sampling locations ($p = 0.0004$). Median dog allergen declined from 0.72 $\mu\text{g}/\text{m}^2$ to 0.35 $\mu\text{g}/\text{m}^2$ dog allergen, with concentrations lower in 75% of locations ($p = 0.041$). However, mass fraction of dog allergen in floor dust declined in only 55% of sampling locations ($p = 0.824$). While the median total dust surface density also declined (from 0.29 to 0.23 g/m^2), concentrations were lower in only 60% areas ($p = 0.50$).

DISCUSSION

Allergen Concentrations

Cockroach allergen concentrations were low. All the samples were below the detection limit for Bla g 1 cockroach allergen, except one sample that was less than any published risk level. Studies in more temperate regions of the United States have detected cockroach allergens in schools and child care centers. Of the 14 studies that reported cockroach allergen concentrations,^(3,5,13,14,24,28–36) average allergen concentrations exceeded 2 units/g in five studies (all in schools) with another five studies reporting one or more sample greater than 2 units/g or 5 $\mu\text{g}/\text{g}$.

TABLE VI. Child Care Allergen Concentration Before and After Interventions

Contaminant	Median Baseline	Median Follow-Up 6 Months	Median Follow-Up 12 Months	No. Sampling Locations Declined at Follow-Up 12 Months	Sign Test p-value
N	20	20	20		
Cat ($\mu\text{g}/\text{m}^2$)	1.2	0.70	0.20	95%	0.00004
Dog ($\mu\text{g}/\text{m}^2$)	0.72	0.74	0.35	75%	0.041
Dust (g/m^2)	0.29	0.29	0.23	60%	0.50

The lower levels identified in this study may be due to factors such as Minnesota's climate, building construction, and the existence of pest management practices in the buildings. Cockroaches have been detected in some dust samples collected in Minneapolis schools and homes.^(14,37)

Dust mite allergen concentrations were generally low, but 11% of the samples had Der f 1 $\geq 2 \mu\text{g}/\text{g}$. Of the 26 studies that reported dust mite allergens,^(2,3,5,6,8,9,11,13,14,24,26,28,30,32,33,35,38–50) 5 reported average concentrations greater than $2 \mu\text{g}/\text{g}$, and 7 other studies reported one or more sample greater than $2 \mu\text{g}/\text{g}$.

Dust mite allergen concentrations measured in this study may seem high for a northern climate with very cold winters. The 14 school studies from cold northern climates (Scandinavia) reported dust mite concentrations far below $1 \mu\text{g}/\text{g}$. Minnesota, however, is not directly comparable to Scandinavia because summers are typically warmer and may be more humid in Minnesota. Dust mites thrive in humid conditions. In this study, 7% of the winter samples and 30% of the summer samples were above $2 \mu\text{g}/\text{g}$. This correlates with the absolute humidity, which was 2–4 times greater during the summer sampling days in the facilities. While a previous study in Minneapolis schools reported very low dust mite concentrations ($<0.12 \mu\text{g}/\text{g}$),⁽¹⁴⁾ a study of Minneapolis homes found concentrations similar to this study (10% of samples homes had total dust mite concentrations $\geq 2.6 \mu\text{g}/\text{g}$).⁽³⁷⁾

Another notable observation was that 11% of the samples had Der f 1 levels above $2 \mu\text{g}/\text{g}$, while only 0.5% (1 sample) had Der p 1 allergens greater than $2 \mu\text{g}/\text{g}$. Studies have reported higher^(2,24,42) or lower⁽³⁵⁾ Der p 1 concentrations compared to Der f 1. It has been suggested that the dust mite species that produces Der f 1 can thrive in less humid conditions.^(42,43) The data collected in this study support this supposition.

Cat allergen concentrations varied with about half the samples between 1 and $7.9 \mu\text{g}/\text{g}$ and 9% of samples $\geq 8 \mu\text{g}/\text{g}$. The median cat allergen concentration was $0.91 \mu\text{g}/\text{g}$, which is greater than Minneapolis homes with no cats ($0.11 \mu\text{g}/\text{g}$) but much less than Minneapolis homes that had cats ($120.11 \mu\text{g}/\text{g}$).⁽³⁷⁾ Dog allergen concentrations were similarly varied with 35% of samples between 2 and $9.9 \mu\text{g}/\text{g}$ and 5% of samples $\geq 10 \mu\text{g}/\text{g}$. Of the 31 studies that reported cat allergens, seven reported average concentrations $> 1 \mu\text{g}/\text{g}$, and 11 other studies reported one or more sample greater than $1 \mu\text{g}/\text{g}$.^(2–6,8–10,12,14,24,28,30,32,33,35,36,38,39,43,45–47,50–57)

Of the 20 studies that reported dog allergens, 6 reported average concentrations greater than $2 \mu\text{g}/\text{g}$, and 5 other studies reported one or more sample greater than $2 \mu\text{g}/\text{g}$.^(3–6,8,9,12,30,32–36,43,45,47,53,55–57)

The presence of cat and dog allergens in schools and child care can be attributed primarily to the transfer of allergens on people's clothing and other items brought from homes with pets, with higher rates of pet ownership correlated to classroom concentrations.^(12,43,51–53,58,59) In this study, cat and dog allergen concentrations were higher than most other school and child care studies, but comparable to levels reported in other U.S. school studies.^(2,5,24,28,30,32) Higher pet allergen concentrations in U.S. schools can be attributed to higher rates of pet ownership in the United States and possibly other building and maintenance differences.⁽¹⁾

Comparison of Surface and Type of Facility

Carpeting is a significant reservoir of allergens. Carpet in this study had significantly higher cat, dog, and fungal concentrations compared to vinyl tile both in units of allergen surface density ($\mu\text{g}/\text{m}^2$) and mass fraction of allergen in floor dust ($\mu\text{g}/\text{g}$). Carpet levels were higher due to greater overall dust mass and greater mass fraction of allergen in the floor dust. A number of other school and child care studies have also reported significantly higher concentration of cat, dog, and dust mite allergens in carpet compared to hard/smooth floors, with concentrations 2–7 times greater in carpet in units of mass fraction of allergen in floor dust ($\mu\text{g}/\text{g}$) and 11–240 times greater in units allergen surface density ($\mu\text{g}/\text{m}^2$).^(5,11,24,28,32,39,41,52,60–62)

Furniture and other porous materials are significant reservoirs of allergens in rooms where these are present. Furniture in child care centers had significantly higher mass fraction of cat and dog allergen in floor dust than carpet, while allergen surface densities were similar. Pet allergens appear to be transferred from clothing to furniture at a greater rate than to carpeting, presumably due to direct contact between clothing and furniture. Moreover, furniture was cleaned less frequently than flooring in this study. Higher concentration of allergens have been reported in furniture in other studies, such as curtains,^(9,43) chairs and tables,^(42,53) upholstered furniture,⁽³⁸⁾ bedding,^(3,11) and a combination of fleecy furnishings.^(7,8)

Both schools and child care facilities can have elevated concentrations of indoor allergens. Previous studies reported

higher cockroach allergens in schools than in child care centers. This may be because many of the school studies sampled in food preparation areas, while the child care studies sampled in classrooms.

On the other hand, child care facilities had higher measured dust mite concentrations. This may be because bedding and other fleecy materials were sampled in child care studies—these materials are more ubiquitous in child care centers. One study specifically compared the two types of facilities and found higher cockroach but lower dust mite allergen concentrations in schools.⁽³⁾

Previous studies found similar cat and dog allergen concentrations in both child care and schools. In this study, carpet concentrations in child care centers and schools were surprisingly similar despite differences between the two types of facilities and the season that sampling was conducted. The overall potential for exposure to allergens was greater in child care centers due to the larger numbers of fleecy materials (upholstered furniture, cushions, toys), contact with bedding materials, and the greater number of areas with carpeting.

Concentrations Before and After Interventions

After the baseline sampling and observational building assessments, the schools and child care centers were presented a variety of recommendations to improve the indoor environment. The facilities implemented a variety of interventions, and some of the observed interventions would be expected to impact allergen levels (Table IV).

Statistically significant declines in allergen mass fraction in floor dust were observed for cat and dog allergens in schools and cat allergen (but not dog allergen) in child care centers. The overall measured dust levels also declined slightly but not significantly, and the number of rooms with observed cleaner floors also increased (Table IV).

Findings suggest that the interventions implemented impacted both the pet allergen mass fraction in floor dust and the total dust surface density. Pet allergens are present on small particles (many <10 microns).^(20,22,23) Many of the improvements implemented in the facilities—such as HEPA vacuuming, higher efficiency HVAC filtration, increased filtered outdoor air exchange, damp cleaning, fewer stuffed toys, fewer fleecy furnishings—would be expected to affect smaller particulates such as pet allergens transferred to school by occupants.^(1,18,19)

There are several cross-sectional studies in the scientific literature that assessed conditions in different educational facilities at a moment in time and found an association between lower allergen concentrations (surface density and/or allergen mass fraction in floor dust) and specific environmental conditions, such as cleaning and housekeeping factors. For example, child care facilities with allergen avoidance measures in place—no carpeting, daily floor cleaning, weekly laundering of sheets, monthly cleaning of soft toys, and synthetic mattress covers—had low or very low levels of allergens (generally much less than 2 $\mu\text{g/g}$) compared to regular child care facilities.⁽⁹⁾

Other studies have reported a correlation between lower allergen concentrations and increased ventilation,^(11,32,53,54) newer flooring,⁽⁴⁰⁾ fewer open shelves,⁽⁶³⁾ efficient cleaning tools (e.g., new HEPA vacuums),^(40,42,53,54,63) thoroughness of cleaning,^(8,53,63,64) frequency of cleaning,^(11,55) and use of mattress covers.⁽⁸⁾

A few studies used a longitudinal approach similar to this study. Munir et al.⁽⁴⁾ found that changes to ventilation, cleaning frequency, cleaning thoroughness, fleecy items, and vacuum cleaners resulted in a 90–95% reduction in cat and dog allergens. Franke et al.⁽⁶⁵⁾ reported that implementing an effective routine cleaning program involving deep cleaning of flooring, furniture, fixtures, windows, and nonclassroom areas, followed by improved routine cleaning reduced contaminants significantly—levels of dust, volatile organic chemicals, bacteria, and fungi declined 29% to 84%. Pesonen-Leionenen et al.⁽⁶⁶⁾ observed that cleaning of floors and easily accessible horizontal surfaces reduced classroom dust levels by 21–42%. Walinder et al.⁽⁴⁷⁾ found that increasing the cleaning of desk surfaces was associated with less nasal congestion and signs of allergic reactions.

Risk Characterization

The indoor allergens measured in Minnesota schools and child care centers exceeded the provisional threshold for allergic sensitization in many locations and also exceeded the threshold associated with asthma symptoms in some locations.^(18–25) The risk thresholds are evolving. The house dust mite risk thresholds of 2 $\mu\text{g/g}$ for sensitization (in atopic individuals) and 10 $\mu\text{g/g}$ for symptoms, arguably, are the best supported by epidemiologic data and are broadly accepted. Proposed cockroach sensitization/symptom thresholds vary from 1–10 units/g. Previously, the proposed cat sensitization and dog sensitization thresholds were 8 and 10 $\mu\text{g/g}$, respectively. Recently, the U.S. Department of Housing and Urban Development proposed lower thresholds for cat and dog sensitization and asthma symptoms,⁽¹⁸⁾ which were used to organize data as shown in Figure 1.

The direct application of the risk thresholds to schools may not be appropriate. The thresholds were developed using exposure assessment data from the home environment where air exchange rates are lower and individuals are typically more exposed to reservoirs of allergens, such as bedding, upholstered furniture, and stuffed toys. These reservoirs are less prevalent in schools.

On the other hand, child care centers typically have these allergen reservoirs, and the buildings frequently have no or low mechanical air exchange. Hence, the application of the risk thresholds seems more appropriate for the child care environment. Even if the application of the risk thresholds may not be directly relevant to schools, elevated cat and dog allergen should be considered “contaminants” if concentrations are significantly greater than levels found in comparable homes with no such pets. In one large U.S. study, the average levels found in homes that do not have these animals were 1.3 $\mu\text{g/g}$ for dog allergen and 3.8 $\mu\text{g/g}$ for cat allergen.⁽⁶⁷⁾

Mass fraction of allergen in floor dust is the commonly used metric for the environmental assessment of potential exposure risk. Air sampling would be preferable but is technically and logistically challenging. It would also be superior for researchers to report allergens per unit surface area, but there is no standardized collection method that allows for comparison between studies.

In this study, linear regression of data in units $\mu\text{g}/\text{m}^2$ correlated to $\mu\text{g}/\text{g}$ and the curves for cat and dog allergen were similar. Using their respective linear regression formulas, 10 $\mu\text{g}/\text{g}$ of allergen concentrations was corresponded to 1.9 $\mu\text{g}/\text{m}^2$ and 2.0 $\mu\text{g}/\text{m}^2$, for Fel d 1 cat and Can f 1 dog allergen, respectively. These allergen surface density ($\mu\text{g}/\text{m}^2$) thresholds are specific to the sampling methods used in this study.

Analyzing mass fraction of allergen in floor dust should continue to be used for potential exposure assessment purposes until air and allergen surface density ($\mu\text{g}/\text{m}^2$) risk thresholds have been further researched and sampling methods standardized. When comparing different surfaces or evaluating the effect of environmental changes within a study, it is superior to use allergen surface density ($\mu\text{g}/\text{m}^2$) (as long as the sampling method is standardized within the study). This is a better estimate of the total allergen load (i.e., burden) in a room.

When reacting to specific allergic health concerns in relation to a school or child care environment, attention should first be directed to the individual's home or other environment where the most time is spent. This is especially important for individuals allergic to pets—homes with cats or dogs may have more than 100 times the concentrations compared to schools. Depending on the individual's sensitivity, effective intervention in homes may involve the removal of pet (for cat and dog allergies), frequent and thorough cleaning (for a broad spectrum of allergies), controlling humidity (for mold and dust mite allergies), and using allergen-proof covers (for dust mite allergens).

If symptoms persist after effective environmental interventions have been implemented in the home environment, then attention should turn to the school. Allergen sampling is not recommended initially to investigate exposure in the school environment. While it may be helpful to complete allergen sampling to convince decision makers, it is preferable to devote resources to improving facilities maintenance and the implementation of an indoor environmental quality management program, such as the U.S. Environmental Protection Agency's Tools for Schools program.⁽⁶⁸⁾

Strengths and Limitations

There are several strengths to this study. The study design was longitudinal in contrast to the cross-sectional methods used in most other studies. The improvements identified were directly observed by the authors of this study during the course of walk-through inspections (shown in Table IV), unlike some other studies that used only information reported by building staff. School and child care staff were able to reduce

allergen levels in their indoor environments with their existing budgets and staffing resources, unlike some other studies where the investigators conducted or funded the interventions. The improvements were measured in two types of educational facilities: (1) schools and (2) child care centers. These facilities were evaluated separately during different seasons and years. The school buildings (but not child care centers) selected were located in both rural and urban areas in Minnesota, and both the schools and child care centers varied in size, construction, and mechanical ventilation. This indicates some measure of reproducibility of interventions.

There are also limitations to this study. The study was somewhat small with 13 buildings assessed in two subcategories of six schools and seven child care centers. Unlike the school buildings, all the child care centers were located in the city of Minneapolis. A total of 204 samples were collected, but subsample sizes were small when conducting certain analyses. Exposure to allergens is inferred from settled dust samples—air sampling would be preferable but is fraught with complications as described in the Risk Characterization subsection and previously.⁽¹⁾ Detection limits could have been lower to allow for more sensitive data analyses and the inclusion of cockroach and dust mites in analyses of allergen distribution and interventions. A number of allergens were not evaluated that may have been used as outcome measures, such as specific fungal allergens (e.g., Alt a 1), other cockroach allergens (e.g., Per a 1), and mouse allergens (e.g., Mus m 1). In addition, each building received a unique set of recommendations tailored to the buildings' needs, resulting in "treatments" (i.e., interventions) that differed in each building. Finally, data were not distributed normally, requiring the use of nonparametric statistical analyses rather than more robust parametric tests.

CONCLUSIONS

Occupants may be exposed to cat, dog, and dust mite allergens in schools and child care facilities. A broad spectrum of environmental interventions is needed to yield a significant reduction in levels of cat and dog allergens. While these interventions may also impact other biological contaminants (dust mites, fungi, bacteria, pest allergens), more direct interventions are also needed to significantly control these infestation-type indoor contaminants.

It is reasonable to presume that cat, dog, and, to a lesser extent, dust mite allergens are ubiquitous in schools and child care facilities that have various conditions, such as high pet ownership, inadequate cleaning, poor HVAC maintenance, allergen reservoirs (e.g., clutter, porous materials, upholstered furniture), absence of high-efficiency HVAC filters and vacuum cleaners, inadequate outdoor air exchange, and flooring in poor condition. This study has shown that motivated and informed school staff can implement environmental changes with existing in-house resources that yield measurable outcomes.

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